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EUROPEAN ELM SCALE (HOMOPTERA: ERIOCOCCIDAE) ABUNDANCE AND PARASITISM IN NORTHERN CALIFORNIA

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Abstract.—European elm scale, *Gossyparia spuria* (Modeer) (= *Eriococcus spurius*) (Homoptera: Eriococcidae), infested elms (*Ulmus* spp.) at all 12 sites that we sampled in northern California during 1987–1989. Scales were more abundant on English elm (*Ulmus procera* Salisbury) than Siberian elm (*Ulmus pumila* L.). Female scale density peaked at 301 (SD = 76) degree-days above 11° C accumulated from 1 March, mid-April through June depending on location and weather. Scale density and defoliation by elm leaf beetle, *Xanthogaleruca* (= *Pyrrhalta*) *luteola* (Muller) (Coleoptera: Chrysomelidae) were apparently associated. We reared one to three species of parasitoids from scales at each of five locations. We found no parasitoids at seven other sites. Only one species, *Coccophagus insidiator* (Dalman) (Hymenoptera: Aphelinidae), has previously been reported as established on European elm scale in California. We recovered *Trichomasthus coeruleus* Mercet (Hymenoptera: Encyrtidae) at two locations; this species at the time of introduction was apparently misidentified as *Trichomasthus cyanifrons* (Dalman). Both *Trichomasthus* species may have been introduced, but we recovered only *T. coeruleus.* A *Microterys* sp. (Encyrtidae) of unknown origin occurred at two locations. Limited parasitoid distribution and high scale populations at some sites provide an excellent opportunity for further biological control efforts against European elm scale.

Key Words.—Insecta, *Eriococcus spurius, Coccophagus insidiator, Trichomasthus coeruleus, Xanthogaleruca luteola,* biological control, *Gossyparia spuria*

European elm scale, *Gossyparia spuria* (Modeer), is of Palearctic origin and was first discovered in the western U.S. on the Stanford University campus in Palo Alto, California in 1893 (Herbert 1924). Scales mature on bark in the spring, developing into tiny white "cocoons" containing males or purple to dark brown females partially enclosed by a white, waxy fringe. Crawlers emerge from females and settle on leaves or bark where they feed through the summer before moving to overwinter on bark. High populations of this univoltine pest produce copious honeydew and branch dieback.

Classical biological control of European elm scale was conducted in California from 1939 through the mid-1950s. One introduced species, *Coccophagus insidiator* (Dalman), was recovered and reportedly controlled scales at the one site where it was established (Flanders 1952). Finding no published data on European elm scale and parasitoid populations in California since the 1950s, we investigated the current status of the scale and its biological control agents in northern California.

MATERIALS AND METHODS

Scale Abundance.—We sampled European elm scales at 5 northern California sites during 1987, 8 locations in 1988, and 7 sites during 1989 (Figs. 1 and 2), a

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total of 12 different locations were used (Fig. 5). We examined 30 cm long branch terminals and recorded the presence or absence of apparently viable female scales about every 2 weeks during the spring and early summer from an average of 3 to 4 elms (*Ulmus* spp.) at each site. We sampled 40 terminals per tree (5 each from the inner and outer half of the canopy in each cardinal direction) from the lower one third of the canopy of each tree, except in Cloverdale and Hopland where we collected 24 terminals per tree (3 each inner and outer half in each cardinal direction). We determined the proportion of infested terminals ($\bar{x}$; SD) for 1987 by pooling samples within each inner and outer quadrant (8 per tree as above) and by pooling samples by tree during 1988 and 1989. Unless otherwise stated, we report scale densities for each site and species by pooling samples on the date when the maximum proportion of terminals were infested.

We used degree-days as a standard among sites to compare when the maximum proportion of terminals were infested by female scales. Because no studies on development rate or threshold temperature have been reported for *G. spuria,* we used the same model developed for elm leaf beetle, *Xanthogaleruca luteola* (Muller). We accumulated degree-days beginning 1 Mar each year using the single sine wave method and daily maximum and minimum temperatures obtained from recorders near our study sites (Dreistadt & Dahlsten 1990). We employed a lower threshold temperature of 11° C, the same as for elm leaf beetle and intermediate to the threshold determined in California for two other scales: San Jose scale, *Quadraspidiotus perniciosus* (Comstock) with a threshold of 10.6° C (Jorgensen et al. 1981) and California red scale, *Aonidiella citri* (Maskell), with a threshold of 11.5° C (Yu & Luck 1988).

We compared means with *t*-tests using STAT-SAK (Dallal 1986).

Elm Leaf Beetle Relationship.—We investigated the relationship between defoliation by elm leaf beetle and the density of female scales. We sampled elm leaf beetle damage at 1 to 3 week intervals from spring until beetles largely disappeared in the fall using the same terminals that were inspected for scales. For each sample, we rated leaf area consumed from 0 to 10, where 10 is 100% or total defoliation (Dreistadt & Dahlsten 1989). We performed least squares linear regressions using PROC REG (SAS Institute Inc. 1988) to correlate beetle defoliation with scale density. We pooled samples by date for each tree and compared the maximum proportion of scale-infested terminals versus maximum beetle defoliation. We regressed maximum defoliation against maximum scale density during the same year and maximum defoliation during the current year against maximum female scale density the subsequent year. We conducted separate regressions for each elm species for all sites and years pooled.

Parasitism.—During 1988 and 1989, we clipped and returned to the laboratory the terminals sampled as above. We also randomly collected scales in Albany (Alameda Co.) from five Chinese elm (*Ulmus parvifolia* Jacquin) on 3 dates in May and June, 1990. We clipped a 3–6 cm long section of twig containing one or more female scales from each infested terminal and placed it in a 22 by 93 mm cotton-stoppered shell vial. We held vials at 21–27° C 16:8 (L:D) during 1989 and 1990, and at about 24° C and uncontrolled artificial and diffuse natural light during 1988. Any European fruit lecanium, *Parthenolecanium corni* (Bouche) or black scale, *Saissetia oleae* (Olivier) present were scraped off before holding samples for emergence. We recorded the number of scales in each sample and the emergence of any crawlers or parasitoids. To detect any unemerged parasitoids, we dissected scales without emergence after 3 or more months.

We report apparent parasitism at each site for all sample dates pooled during the two month period when female univoltine scales were found to be most abundant. We determined apparent parasitism by dividing the number of parasitized scales by the sum of parasitized and viable scales, then multiplying by 100. Parasitized scales were those from which parasitoids emerged or from which they were dissected. Viable scales were those from which crawlers emerged in the laboratory. Some samples contained scales that were too immature when collected to produce crawlers or from which all crawlers or parasitoids had emerged before they were collected; we excluded these from parasitism estimates. For twig samples producing crawlers and containing more than one unparasitized scale, we did not determine whether one or more than one of the unparasitized scale had produced crawlers. For these samples, we estimated the number of viable scales (V):

$$V = pVs \times N$$

where N is the number of unparasitized scales in each sample with crawlers and pVs is the proportion of viable scales in all samples pooled from that date and location that contained only one unparasitized scale.

Parasitoid introduction data through 1950 (Table 2) are from Flanders (1952); those data from 1952–1956 are from *Biological Control of Elm Scale,* unpublished University of California colonization reports from Riverside and the Gill Tract in Albany authored by R. L. Doutt, S. E. Flanders, and T. W. Fisher from 15 Jul 1952 through 15 Jul 1956 and summarizing work conducted in part by K.S.H.

We identified *Trichomasthus coeruleus* Mercet using the published keys and descriptions of Mercet (1921, 1923), Nikol'skaya (1952), Graham (1958, 1969a), Alam (1957), and Jensen & Sharkov (1989). Publications used to identify the other parasitoids were: *C. insidiator* (Compere 1931), *Microterys* sp. males (Trjapitzn & Gordh 1978), *Microterys* sp. females (Tryapitsyn & Gordh 1978), *Tetrastichus* sp. (Burks 1943), and *Pachyneuron* sp. (Graham 1969b). We sent specimens of the former three genera to the Taxonomic Services Unit (TSU), USDA-ARS, Beltsville, Maryland for confirmation of identification. We deposited voucher specimens from our recoveries in the Bohart Museum, University of California, Davis.

Results and Discussion

Scale Abundance.—European elm scales occurred at all 12 of our northern California study sites. Scales were more abundant on English elm, *Ulmus procera* Salisbury, than Siberian elm, *Ulmus pumila* L. in Adin (t = 27.7; n = 240; P < 0.001) and Susanville (t = 22.2; n = 320; P < 0.001), where we sampled both host species during 1987 (Figs. 1 and 2). Significantly more English elm terminals were infested than Siberian elm terminals when samples from all sites on all dates were pooled during 1987 (t = 46.9; n = 2,625; P < 0.001), 1988 (t = 54.4; n = 2,340; P < 0.001), and 1989 (t = 50.2; n = 5,938; P < 0.001), but climate and natural enemy differences among sites may partly account for this (see below). Significantly more American elm, *Ulmus americana* L., terminals were scale infested than Siberian elms in Princeton during 1988 (t = 226.0; n = 120; P < 0.001) and 1989 (t = 26.2; n = 160; P < 0.001), but too few American elms were

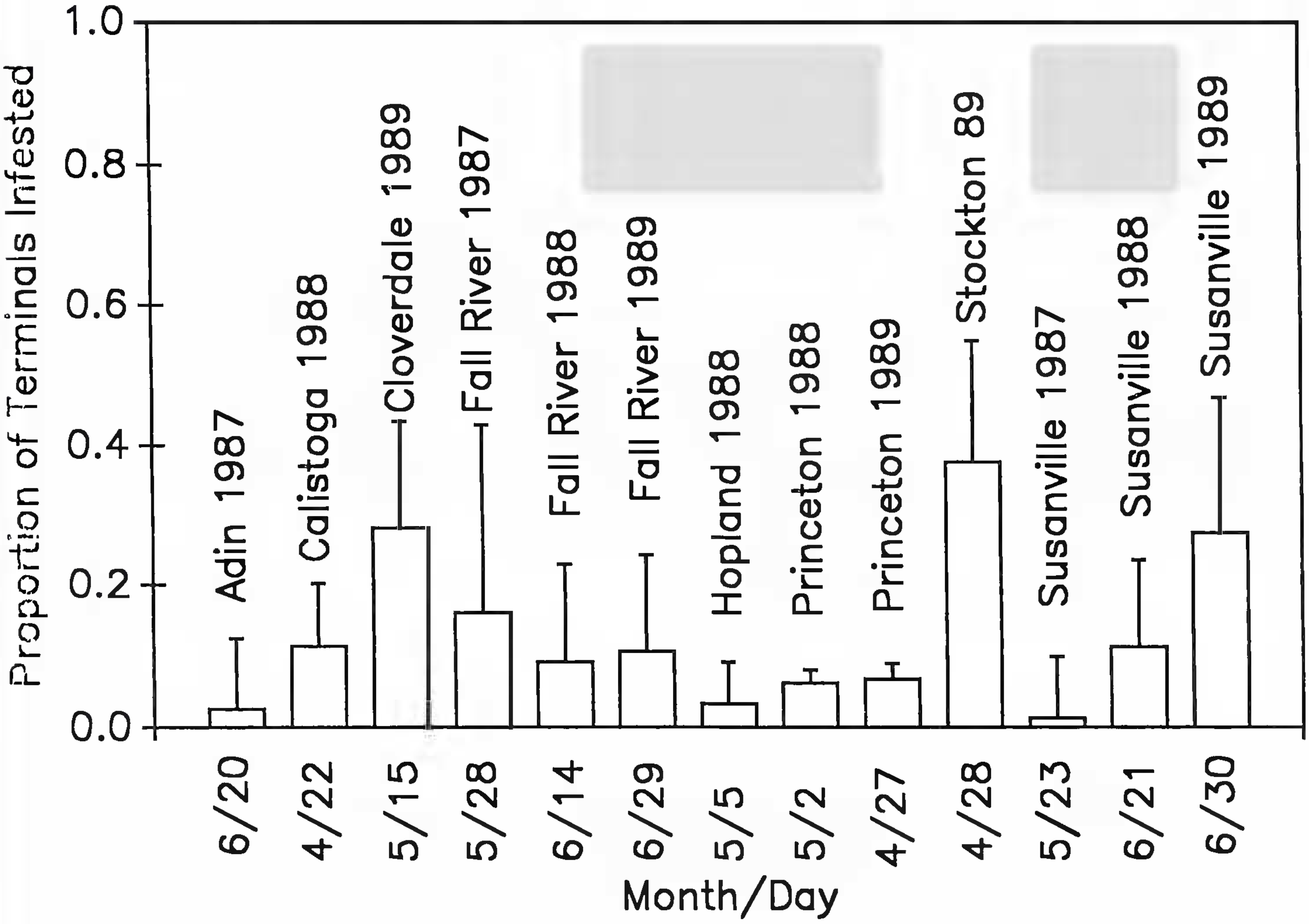

Figure 1. Mean (+ SD) proportion of Siberian elm branch terminals (30 cm long) infested with apparently viable female European elm scales on the sample date of maximum infestation.

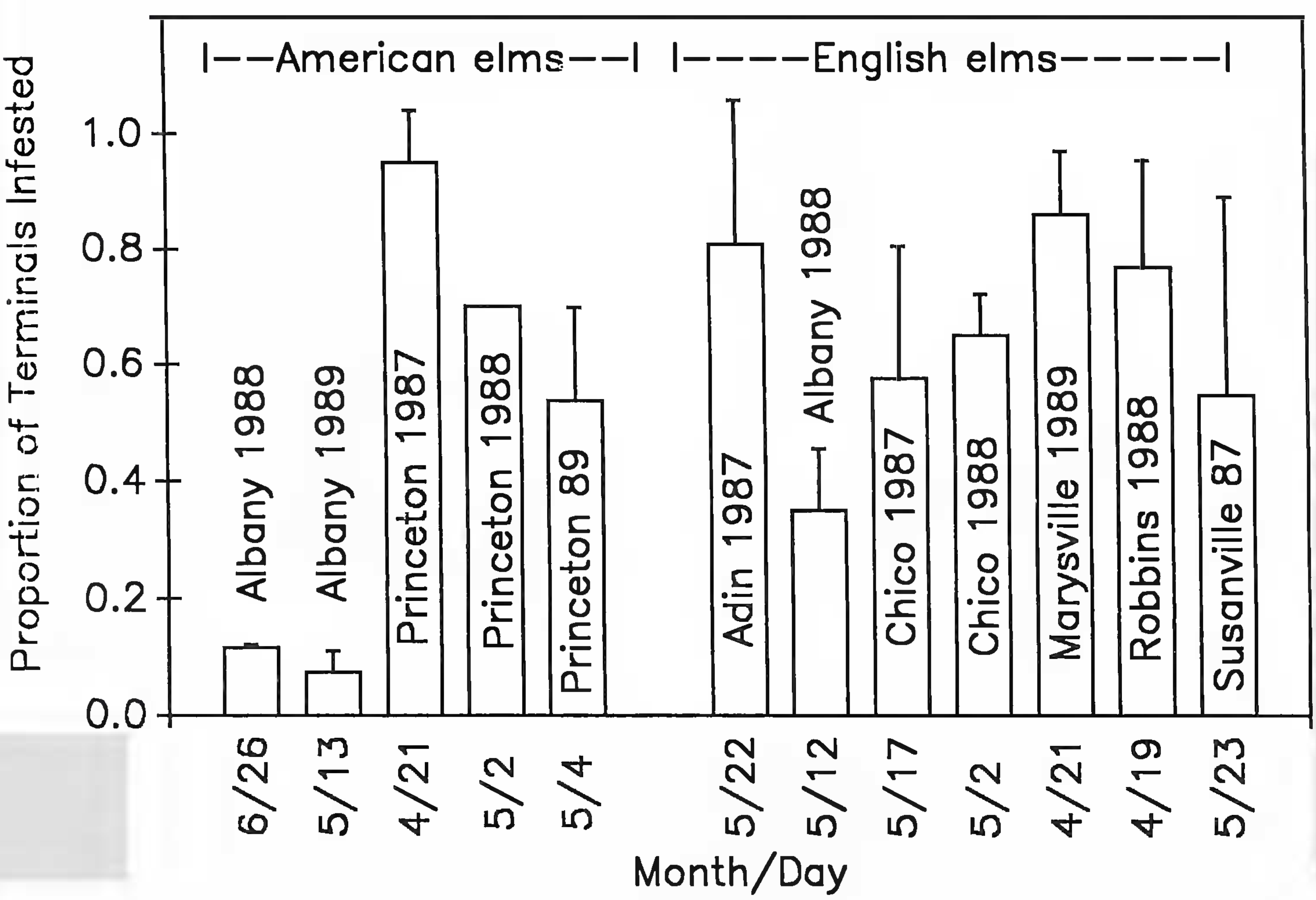

Figure 2. Mean (+ SD) proportion of American elm and English elm branch terminals (30 cm long) infested with apparently viable European elm scales on the sample date of maximum infestation.

sampled to generalize about their susceptibility to scales relative to the other elm species.

The maximum proportion of infested terminals occurred about 10 June (SD = 16 days) in northeastern California (Adin, Fall River Mills and Susanville), which was significantly later (t = 5.3; n = 25; P < 0.001) than all other sites pooled, where infestations peaked about 5 May (SD = 16 days). Northeastern sites are intermountain valleys with colder winters and a shorter growing season than other study locations. Because of the varying climate among our sites, which span about 500 km and range from about 10 to >1200 m above sea level, we used degree-day accumulations to compare peak scale occurrence. The maximum proportion of infested terminals in northeastern California, other sites, and all sites pooled occurred at 301 (SD = 76), 305 (SD = 96), and 303 (SD = 89) degree-days, respectively; differences were not significant (P > 0.05). Degree-days accumulations can assist in timing scale population monitoring, parasitoid collections and releases, and insecticide applications. However, laboratory development rate and threshold temperature data should be developed for *G. spuria* to validate our estimates (see Materials and Methods).

Elm Leaf Beetle Relationship.—We observed and photographed scale nymphs and elm leaf beetle larvae feeding on the same leaves. Because beetles can prematurely defoliate elms before scale nymphs would normally migrate in fall from leaves to bark, we hypothesized that high defoliation would reduce scale densities the subsequent season because many scale nymphs would die on leaves that are killed or drop because of beetle feeding. We observed the opposite effect; maximum beetle defoliation during the current year was positively correlated with maximum female scale density during the next year on English elm (F = 15.7; n = 6; P < 0.05) (Fig. 3B). American elms that experienced little beetle feeding also had lower scale densities, but results may have been an artifact of small sample size. The apparent association between beetle feeding and scale density may be because trees are similarly predisposed to attack by both pests; for example, English elms are more susceptible to both elm leaf beetle (Dreistadt & Dahlsten 1989) and European elm scale than are Siberian elms (Fig. 3). Stress associated with beetle damage may increase elm susceptibility to scales, or vice versa.

There was no association between current season beetle defoliation of Siberian elm and female scale density the subsequent year (Fig. 3B). Siberian elm foliage growth is indeterminate and anytime from spring through fall trees will drop individual leaves that are partially damaged by beetle feeding, leaves that may also contain scale nymphs. English and American elm growth is determinate. Trees retain damaged leaves, dropping most foliage over a short period after damage becomes severe then sometimes growing a second flush of foliage; retention of damaged leaves may allow scale nymphs to move from foliage to bark before leaves drop.

The maximum proportion of female scale-infested terminals was correlated with maximum beetle defoliation during the same season on English elms (F = 5.3; n = 25; P < 0.05) and Siberian elms (F = 4.1; n = 40; P < 0.05); however, R^2 values were very low (Fig. 3A) and it is unlikely that female scale density on twigs is affected by beetle feeding during the same season because scales mature and produce crawlers in the spring and maximum beetle defoliation occurs later in summer. The distribution, abundance, and behavior of scale nymphs on bark

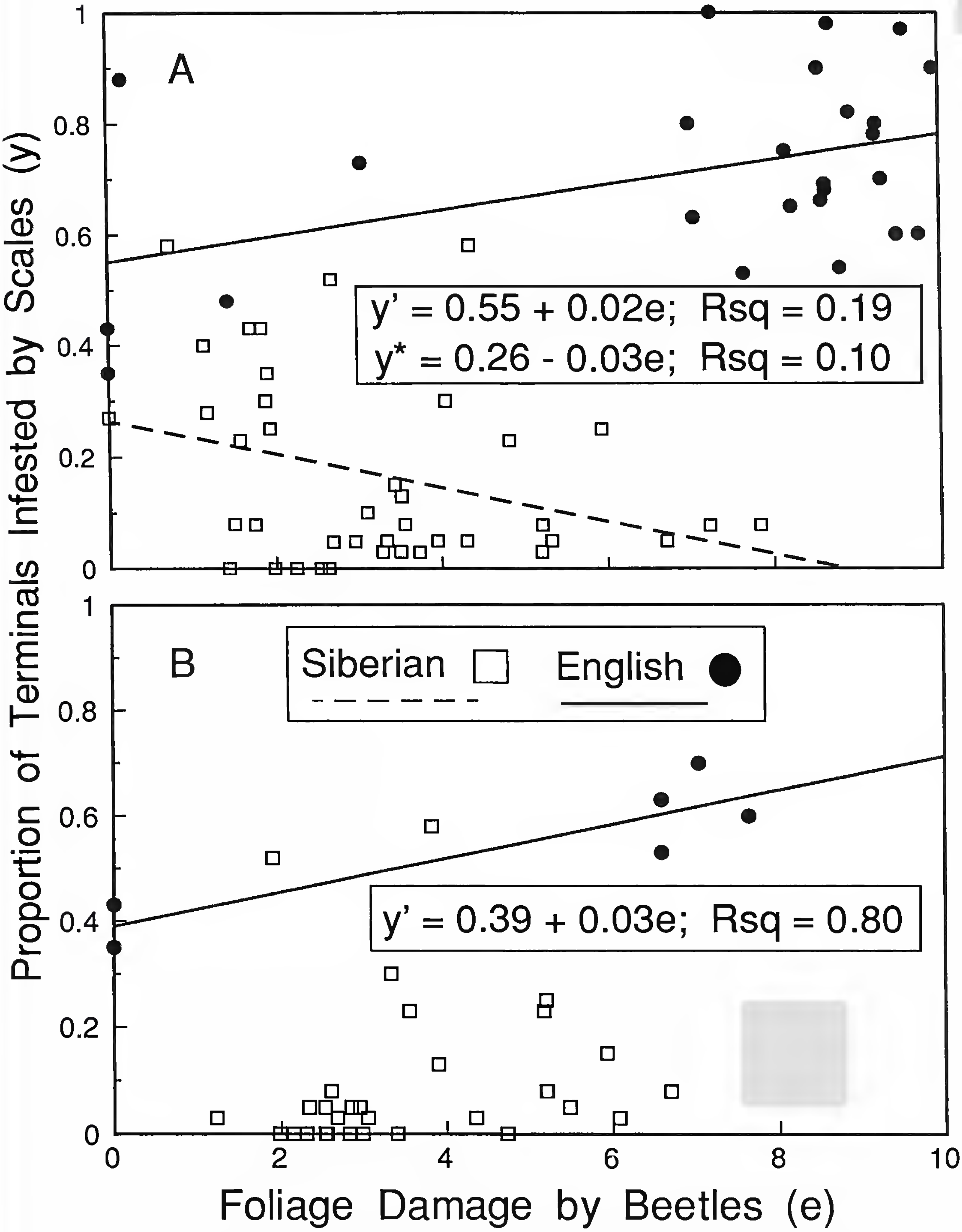

Figure 3. Foliage damage by elm leafbeetle (e), rated 0 to 10 where 10 = 100%, and A) proportion of terminals infested with female scales during the same season or B) proportion of terminals infested with scales during the next season on English and Siberian elms in northern California, 1987–1989. Significant ($P < 0.05$) regression equations are shown for English elm (y') and Siberian elm (y*).

Table 1. Apparent parasitism of European elm scale in northern California, 1988–1990.[a]

Location	Year	Sp	n	Percent parasitism $\bar{x}$	Percent parasitism SD	Percent of total parasitism by species: *Coccophagus insidiator*	*Trichomasthus coeruleus*	*Microterys* sp.	Other[b]	Mummy[c]
Adin	1988	E	87	15.9	35.7	90	0	0	0	10
Adin	1988	S	108	59.7	39.1	85	0	0	0	15
Adin	1989	S	202	9.9	24.5	42	0	0	0	58
Albany	1988	A & E	245	0	0	0	0	0	0	0
Albany	1989	A & E	123	0	0	0	0	0	0	0
Albany	1990	C	345	1.1	6.3	0	100	0	0	0
Fall River	1988	S	287	1.5	10.5	100	0	0	0	0
Fall River	1989	S	204	2.9	14.1	100	0	0	0	0
Stockton	1988	S	168	13.4	33.8	0	67	0	33	0
Stockton	1989	S	851	4.6	16.3	0	81	14	0	5
Susanville	1988	E	35	11.1	32.3	100	0	0	0	0
Susanville	1988	S	148	0	0	0	0	0	0	0
Susanville	1989	E	72	18.1	34	43	0	14	0	43
Susanville	1989	S	828	12.6	27.2	44	0	24	2	30

[a] Host species (Sp) are American elm (A) English elm (E), Siberian elm (S), or Chinese elm (C); n is number of viable scales + parasitized scales sampled.

[b] Other species are apparently secondaries: *Tetrastichus* sp. (in Stockton); *Pachyneuron* sp. (Susanville).

[c] Parasitoids dissected from mummified scales were not identified.

and leaves has not been reported and must be investigated in order to better understand the relationship between elm leaf beetle feeding and scale density.

Coccophagus insidiator.—We reared at least three species of primary parasitoids and two apparently secondary species from European elm scale; of these only *C. insidiator* has previously been recovered in California. *Coccophagus insidiator* was the only scale parasitoid in Adin (Modoc Co.) and Fall River Mills (Shasta Co.) and it was the predominant species in Susanville (Table 1, Figs. 4 and 5). In comparison with its univoltine host, *C. insidiator* reportedly has more than one annual generation on female scales and parasitizes overwintering male scales prior to females becoming susceptible (Griswold 1927, Flanders 1952). Nearly all male scales and any parasitoids they may have contained emerged prior to sampling. Generational parasitism (van Driesche 1983) is likely higher than indicated by the apparent parasitism of female scales on any one date (Fig. 4) or from all dates pooled (Table 1).

Coccophagus insidiator was introduced into the southern two-thirds of California through the mid-1950s (Table 2). It was previously reported as established only in Redlands (San Bernardino Co.) in southern California (Flanders 1952); which is about 900 km south of our recoveries. Although we collected many scales in Albany and Stockton (Table 1) and held an average of 370 scales for parasitoid emergence from each of 7 other locations in the Central Valley or coastal valleys of northern California (Fig. 5), we did not detect *C. insidiator* at those locations even though they encompass original release sites (Table 2) and are 300 km or more closer to Redlands than our recovery sites. Our identification of *C. insidiator* was confirmed by M. E. Schauff, TSU, USDA-ARS.

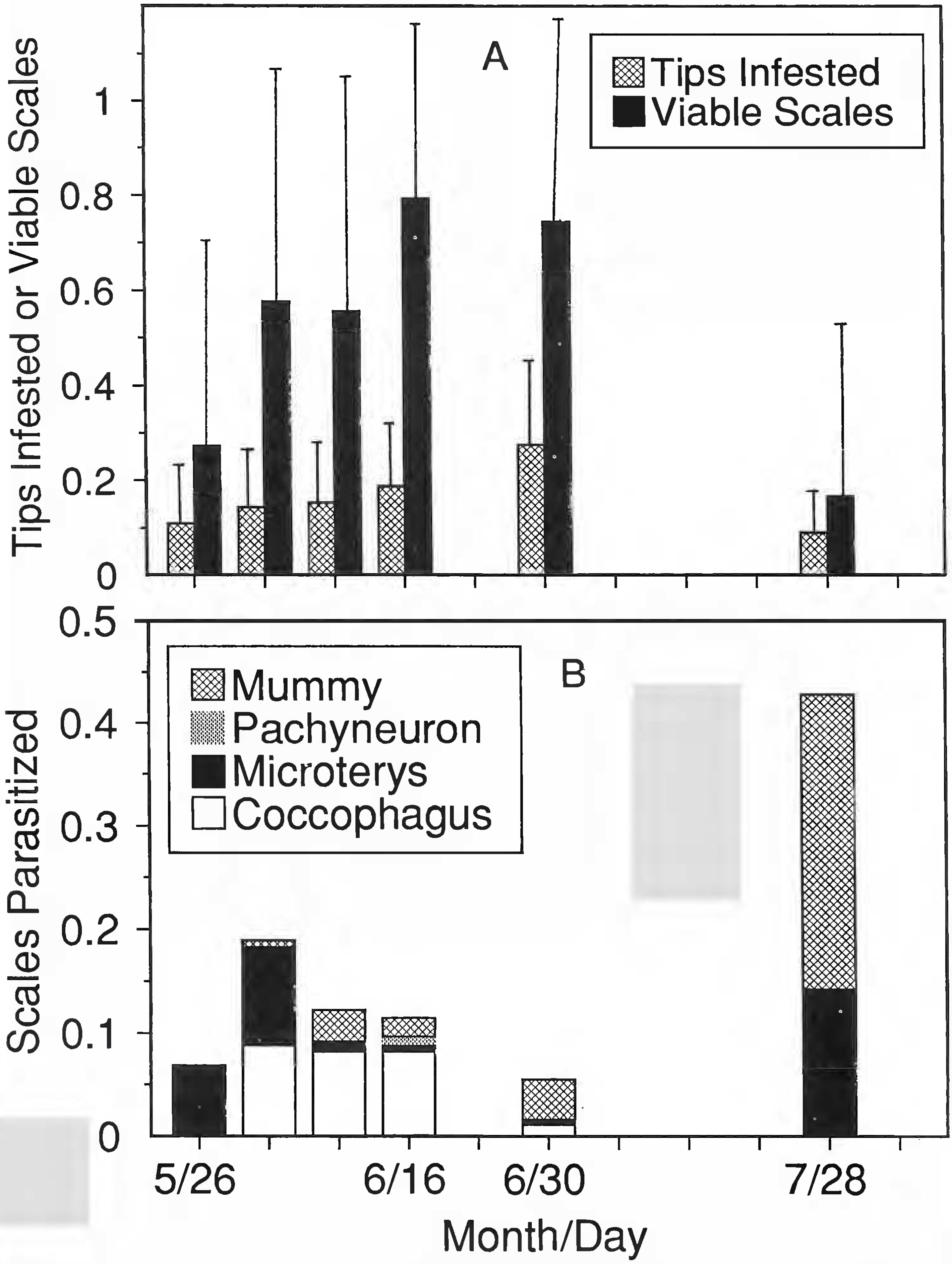

Figure 4. A) Mean (+ SD) proportion of terminals (tips) infested and scales from which crawlers emerged (viable scales) and B) proportion of European elm scales parasitized by three species in Susanville, California, on each sample date in 1989.

Trichomasthus coeruleus.—We recovered *T. coeruleus* in Stockton (San Joaquin Co.), where it was the most abundant parasitoid, and in Albany, where it was the only species parasitizing European elm scale (Table 1). Prior to its introduction in the Central Valley and the San Francisco Bay Area in 1952 and 1954, this

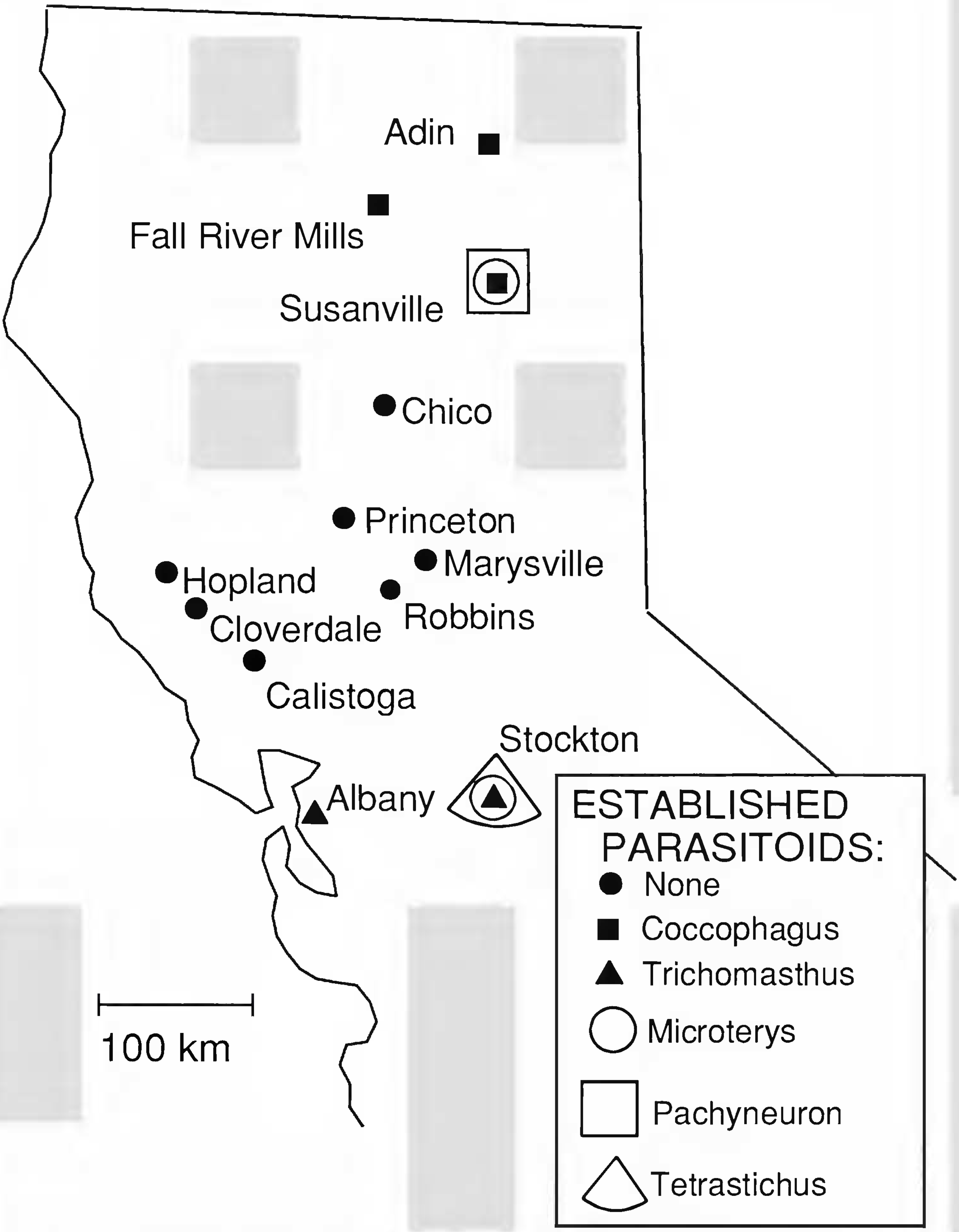

Figure 5. Northern California study sites where three species of European elm scale primary parasitoids (*Coccophagus insidiator, Trichomasthus coeruleus, Microterys* sp.) and two apparently secondary parasitoids (*Pachyneuron* sp., *Tetrastichus* sp.) were found or not detected, 1988–1990.

species was keyed using Mercet (1921) and identified as *Trichomasthus cyanifrons* (Dalman). That key was in error (Mercet 1923). Based on more recent keys and descriptions that distinguish between *T. cyanifrons* and *T. coeruleus,* we believe that the *Trichomasthus* introduced from France into Albany, Berkeley, Madera,

Table 2. Parasitoid introductions reported against European elm scale in California.[a]

Parasitoid species	Release year	Parasitoid source	Number released	Release city (county)
C. insidiator	1939	Italy	50	Los Gatos (Santa Clara)
	1949	France & Germany	175	Redlands (San Bernardino)
			80	San Jose (Santa Clara)
			65	San Anselmo (Marin)
	1950	France & Germany	61	San Anselmo
			78	Berkeley (Alameda)
	1952	France	312	Sacramento (Sacramento)
			27	Berkeley
	1953	Redlands, Calif.	60	Claremont (Los Angeles)
	1954	France	"several hundred"	Albany (Alameda), Berkeley, Madera (Madera)
	1955	Redlands, Calif.	400	San Bernardino (San Bernardino)
			500	Claremont
	1956		310	Claremont
T. cyanifrons[b]	1949	France & Germany	27	Redlands
			13	Balboa (Los Angeles)
			16	Pasadena
	1952	France	39	Sacramento
	1954		31	Albany, Berkeley, Madera
Metaphycus sp.	1954	France	26	Albany, Berkeley, Madera

[a] Source: Flanders 1952 (1939–1950 data); *Biological Control of Elm Scale,* unpublished University of California colonization reports from Riverside and the Gill Tract in Albany (1952–1956).
[b] Probably *T. coeruleus,* see text.

and Sacramento during 1952 and 1954 (Table 2) was *T. coeruleus,* not *T. cyanifrons* as previously reported. The *Trichomasthus* introduced in southern California in 1949 from France and Germany may have been *T. cyanifrons* as reported by Flanders (1952), but we did not recover that species. Ours is the first reported recovery of a *Trichomasthus* species from *G. spuria* in North America. Specimens we sent to TSU were identified as *Trichomasthus* sp.

Microterys sp.—European elm scales in Stockton and Susanville were parasitized by a *Microterys* sp. Two peaks of *Microterys* sp. emergence (early June and late July) were observed in Susanville in 1989 (Fig. 4B), indicating that *Microterys* sp. has more than one annual generation and inflicts greater mortality on its univoltine host than is indicated by apparent parasitism on any one sample date (Fig. 4B) or all dates pooled (Table 1).

An undescribed *Microterys* sp. was imported into quarantine in California in 1949, but only males were produced and no releases were made according to Flanders (1952) and the recollection of K.S.H., who worked on that project. We believe that Clausen (1978) was wrong in stating that "a very few" *Microterys* sp. were released from quarantine and introduced. Clausen (1956) makes no mention of this species even though it discusses releases through 1953 and was published closer to the actual event than Clausen (1978). Morphological distinctions between *Microterys* in Susanville and Stockton indicate they may be different species. At least 8 species of *Microterys* have been reported in California, but their taxonomy is uncertain and this genus of parasitoids is poorly known (Rosen 1976, Gordh

1979). We do not know the origin of our *Microterys* sp. and specimens sent to the TSU were returned as genus and species undetermined.

Biological Control.—Our methods were not designed to assess parasitoid impact; we lacked sufficient time and there were no previous data on scale abundance or the species and distribution of any parasitoids. Differences in climate, elm species, and natural enemy distribution and possible effects from elm leaf beetle defoliation confound efforts to evaluate biological control.

We also recovered three scale feeding Coccinellidae on our study elms: *Hyperaspis quadrioculata* (Motschulsky) in Adin, Fall River Mills and Susanville, *Chilocorus bipustulatus* (L.) in Stockton, and *Rhyzobius forestieri* (Mulsant) in Albany. Predators may also influence scale densities, but our methods were not designed to detect or sample predators or assess their impact.

There is evidence that parasitoids can provide biological control of European elm scale. We excluded Argentine ants, *Iridomyrmex humilis* (Mayr) from Chinese elm branches in Albany in 1990 and 1991 and parasitism by *T. coeruleus* apparently increased and scale densities declined (Dreistadt et al. 1992). Flanders (1952) reported that *C. insidiator* parasitized up to 85% of mature European elm scales in Redlands and significantly reduced host populations there, but he provided no methods or other data.

Flanders (1952) states it is a "well-known fact that elm scale in Europe is under excellent natural control." We found no published data on European elm scale density and parasitism in Europe; however, Burger et al. (1985) report that in 1984 a "heavy outbreak of the uncommon coccid *Gossyparia spuria* (Modeer) occurred at 'S-Gravenhage" in the Netherlands and that this may have been a secondary pest problem. Conversely, Casado (1985) states that European elm scale is, "another weakening factor to add to the very severe problems that the elm stands [around Madrid, Spain] already have."

Because of the copious and annoying honeydew it excretes, European elm scale infested elms have been treated with insecticide by at least one city (Chico) where we sampled scales but found no parasitoids. There are reports of European elm scale damage or control soon after its introduction in the West (Doten 1908, Herbert 1924) and more recently (Cranshaw et al. 1989).

Conclusions.—Although one to three parasitoid species occurred at each of five of our study sites, no parasitoids were detected at seven locations. Substantial rates of parasitism and the apparently limited distribution of parasitoids in California provides opportunity to introduce and study natural enemies before and after introduction at sites where they are not present. Ant exclusion may improve biological control at locations where parasitoids are established. European elm scale is an excellent candidate for further biological control research.

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